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THERMAL CONDUCTIVITY OF ROCK DRILL CORE ATK-1 FROM THE ATIKOKAN AREA, ONTARIO

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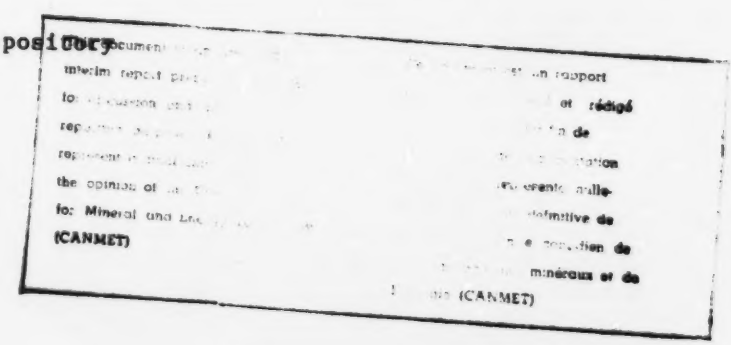
December 1984

Project ERP-4.4.0.3.01
Underground Nuclear Waste Repositories



12 pp
MINERALS RESEARCH PROGRAM
MINERAL SCIENCES LABORATORIES
DIVISION REPORT ERP/MSL 84-160 (TR)

MICROMEDIA MAR 15 1985

THERMAL CONDUCTIVITY OF ROCK DRILL CORE ATK-1 FROM THE ATIKOKAN AREA, ONTARIO

by

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ABSTRACT

Thermal conductivity of three segments from drill core ATK-1 were measured in the temperature range 30°-500°C. Cylindrical specimens were prepared parallel and perpendicular to the axis of the drill core to determine the possible effect of structural irregularities on thermal conductivity.

It was found that there was little difference in the thermal conductivities of rocks from levels close to the surface. Thermal conductivities of rocks from greater depths varied appreciably.

Common to all specimens was a rapid decrease of thermal conductivity with increasing temperature. This characteristic could cause relatively steep thermal gradients and would contribute to thermal instability of the rock mass.

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CONDUCTIVITÉ THERMIQUE D'ÉCHANTILLONS D'UNE CAROTTE DE SONDAGE D'UNE ROCHE ATK-1 DE LA RÉGION DE L'ATIKOKAN EN ONTARIO

par

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RÉSUMÉ

On a mesuré la conductivité thermique de trois échantillons d'une carotte de sondage ATK-1, dans un intervalle de température allant de 30° à 500°C. Les échantillons cylindriques ont été préparés dans les sens parallèle et perpendiculaire à l'axe de la carotte de sondage, dans le but de déterminer l'effet possible des irrégularités structurales sur la conductivité thermique.

On a découvert qu'il y avait peu de différence dans la conductivité thermique des roches venant des niveaux proches de la surface. Toutefois, la conductivité thermique des roches venant de niveaux plus profonds variait considérablement.

Enfin, on a remarqué qu'une diminution rapide de la conductivité thermique avec l'augmentation de la température était une caractéristique commune à tous les échantillons. De plus, cette caractéristique pourrait causer des gradients de température relativement élevés et contribuer à l'instabilité thermique de la masse rocheuse.

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INTRODUCTION

Heat generation due to radioactive decay of irradiated nuclear fuel may continue for a very long time. In the case of CANDU non-reprocessed waste the repository will attain two temperature peaks (1,2,3). The second temperature peak, which may be as high or even higher then the first one, would occur at approximately 10,000 years after the emplacement of the waste. The temperature would remain elevated for many millenia afterwards. Hence, particular consideration should be given to the thermophysical properties of the rocks in which the nuclear waste vault would be built.

Thermal conductivity is an important thermophysical parameter because it establishes the rate at which heat from the radioactive waste would be dissipated through the rock mass. Its absolute value and the rate of change of this value with temperature provides a sensitive measure for evaluating the loading capacity of a repository and the thermal stability of the surrounding rock masses.

Because of the complex nature of rocks and wide variations in texture and composition, prediction of their thermophysical properties is difficult. It is particularly difficult to foresee what changes can occur in thermal transport properties in structured and fractured rocks. To determine the thermal behaviour of the rock mass surrounding the Atikokan borehole ATK-1, thermal conductivity of rock specimens from several levels of the ATK-1 drill core was measured in unconstrained conditions.

PROCEDURES

METHOD OF MEASUREMENT

The thermal conductivity measurements were made in a modified comparative-method thermal conductivity apparatus, the original version of which was described previously (4). The modification consists of a provision for cooling the heat sink and the heat guard. In essence, a 2.54 cm diameter rock specimen, 2.54 cm high, is placed between two standards of the same dimensions. The three cylinders are placed on a cylindrical heat stabilizer, also of the same dimensions. The column consisting of four cylinders is held between the heat source and heat sink with the heat

stabilizer placed next to the heat source. The entire assembly is surrounded by a cylindrical heat guard. By adjusting the power input to the guard heaters wound on the outside of the heat guard, heat flow can be constrained to the axial direction only. Under such conditions the temperature gradients in the cylinders will be inversely proportional to thermal conductivity. As the conductivity of the standards is known, the thermal conductivity of the specimen can be readily calculated.

The measurements were made in the 30°-500°C temperature range. Temperatures were measured with 28 B&S gauge chromel-alumel thermocouples. Pyroceram Code 9606* was used for the standards and the heat stabilizer. All measurements were made at successively increasing temperatures. The temperature gradients within the rock samples were approximately 20°C. The accuracy of the measurements is estimated to be ±5%.

MATERIALS

Specimens for thermal conductivity measurements were prepared from the sections of drill core ATK-1 that was drilled in the Eye-Dashwa Lakes granitic pluton north of Atikokan, Ontario. They were located at levels 79.30 m, 434.17-434.35 m and 1063.50-1097.90 m below the surface. The rock samples were characterized by Soles (5). All the specimens are medium- to coarse-grained (0.1 to 12 mm in diameter), similar in texture and composition. Table 1 gives the composition ranges for rocks from the three levels.

TABLE 1. Composition range of ATK-1 drill core rocks

Mineral	Volume Percentage Range at Level: 79 m	434 m	1063-1098 m
Plagioclase	43.3	41.5	41.8 - 50.2
K-feldspar	31.2	23.3	21.0 - 26.2
Quartz	26.6	22.1	19.6 - 20.7
Biotite	3.6	5.0	0.3 - 5.1
Amphibole	0.1	1.4	1.7 - 2.0
Muscovite	-	0.5	0.2 - 0.6
Epidote	3.1	2.5	1.8 - 2.8
Magnetite, Hemat.	1.1	1.3	1.3 - 2.2
Sphene, Apatite	0.6	1.4	1.6 - 3.0
Calcite	-	0.6	0.0 - 0.6
Chlorite	0.4	0.4	0.2 - 1.9

*Pyroceram Code 9606 is a polycrystalline glass-ceramic made by Corning Glass Works, Corning, New York

A total of eight specimens were prepared for these measurements. To determine the possible grain orientation effect, the cylindrical specimens were cut parallel and perpendicular to the axis of the drill core.

The specimens were prepared in the form of 2.54 cm diameter, 2.54 cm high cylinders. They were ground to a tolerance of ±0.0025 cm with the ends lapped plane and parallel. Each cylinder was provided with two 0.75 mm diameter thermocouple holes, which were drilled radially 12.5 mm deep from the surface to the cylinder's axis at a distance of 1.65 mm from each end.

RESULTS AND DISCUSSION

The results of the thermal conductivity measurements are shown in Figures 1 and 2. The curves were fitted to the data by the least squares method. Each curve represents 10 or more data points. The curves are also represented by the equation:

$$\lambda = a_1 + a_2 t + a_3 t^2$$

where λ is the thermal conductivity in W/cm°C and t is the temperature in °C. The equation is valid between 30° and 500°C. The coefficients a_1, a_2 and a_3, as well as the standard and average deviations are given in Table 2. Symbols (∥) and (⊥) indicate that the principal axis of the cylindrical specimen was parallel or perpendicular with the axis of the drill core, respectively.

TABLE 2. Coefficients for the least squares polynomial and standard and average deviations

Rock Specimen	Coefficients			Deviations, %	
	$a_1 \times 10^2$	$a_2 \times 10^5$	$a_3 \times 10^8$	Standard	Average
1 (⊥) 79.30 m	3.211	-3.913	2.687	1.45	1.70
2 (⊥) 434.17 m	3.336	-4.737	3.946	0.92	0.91
3 (∥) 434.20 m	3.273	-4.903	4.173	0.88	1.25
4 (∥) 434.30 m	3.269	-4.224	3.051	0.80	1.00
5 (⊥) 434.35 m	3.240	-4.320	3.174	0.71	1.00
6 (⊥) 1063.50 m	2.840	-4.786	1.714	1.26	1.97
7 (∥) 1079.00 m	3.087	-4.066	3.215	1.00	1.33
8 (∥) 1097.90 m	3.342	-4.224	3.332	0.98	1.15

Figure 1 shows thermal conductivity of rock specimens from the two levels closest to the surface (1-5). Because of petrographic similarity, it is not surprising that the thermal transport properties of these five rocks are also similar. The small differences in the thermal conductivities are within the experimental error of the apparatus. However, even if they were real the variations in the microcrack distribution would probably have a greater effect on thermal conductivity than the orientation of the specimen. For example, specimens 3 and 4 were prepared from adjacent segments and both were cut parallel to the axis of the drill core, yet it is these two samples that show (particularly in the 200°-300°C range) the largest difference in thermal conductivity.

Thermal conductivity of rocks from the greater depths is shown in Figure 2. The values for specimens 6 and 7 differ at low temperatures but become similar at higher temperatures. In comparison with rocks from the higher levels, the thermal conductivity of specimens 6 and 7 is somewhat lower, although the petrographic characteristics of both groups are similar. However, the samples at greater depths are subjected to higher pressure and when brought to the surface, it may be speculated, the greater pressure relief causes formation of a larger number of microcracks than in the case of rocks located closer to the surface. The larger number of microcracks would be, of course, responsible for an apparently lower thermal conductivity. A previous study (6) has shown that thermal transport properties can be appreciably affected by pressure. Valuable information could be obtained on these rocks by performing measurements under various pressures.

The thermal conductivity of specimen 6 is appreciably higher than that of the other two rocks. In fact it is higher than even that of rocks closer to the surface. The high quartz content of sample 6 (50.2% as opposed to 41-43% for the other rocks) is the most probable cause for its relatively high thermal conductivity.

The thermal conductivity of nearly all rocks is temperature dependent. It mostly decreases with increasing temperature, at least in the 25° to 500°C temperature range. In the case of ATK-1 rocks this decrease is substantial. For instance the conductivity of specimens 1 to 5 is approximately 28% higher at room temperature than that at 200°C. Temperature dependence is also shown by the specimens at the 1000 m level.

This rapid decrease of thermal conductivity with temperature is not a desirable characteristic for rocks surrounding a nuclear repository. When thermal conductivity decreases rapidly with increasing temperature, the ratio between thermal conductivities of the hotter and the cooler layers concentric about the vault would be smaller than in the case of rocks with low temperature-dependent thermal conductivity; consequently, for equal surface temperatures of the confining walls, the temperature gradients would be steeper. Therefore, it can be expected that the thermal gradients around a repository, escavated in a rock mass represented by ATK-1 rock specimens, will be relatively steep, producing a higher concentration of thermally induced stresses over shallower depths at the surface of the repository walls.

SUMMARY AND CONCLUSION

Thermal conductivities of Atikokan rocks from the bore hole ATK-1 were measured in the temperature range 30°-500°C. The results show essentially no difference resulting from either the position or orientation of the specimens from the 80- and 400-m levels below the surface. Two of the three specimens from the 1000-m level below the surface have somewhat lower conductivities than that of the rocks from the higher levels. A possible cause could be formation of a larger number of microcracks in the deeper specimens due to a greater relief of pressure when samples are brought to the surface from greater depths. The relatively high thermal conductivity of the third low-level specimen was attributed to its higher quartz content.

The thermal conductivity of all ATK-1 specimens decreases rapidly with increasing temperature, an undesirable characteristic that may cause relatively steep thermal gradients and high thermally induced stresses in the rocks surrounding a repository.

ACKNOWLEDGEMENTS

The author wishes to express his gratitude to J.A. Soles for selecting and indicating the preferred orientation of specimens as well as

for his advice on petrography of the AKT-1 rocks. Thanks are also due to G.A. MacDonald for preparing specimens and measuring the thermal conductivity.

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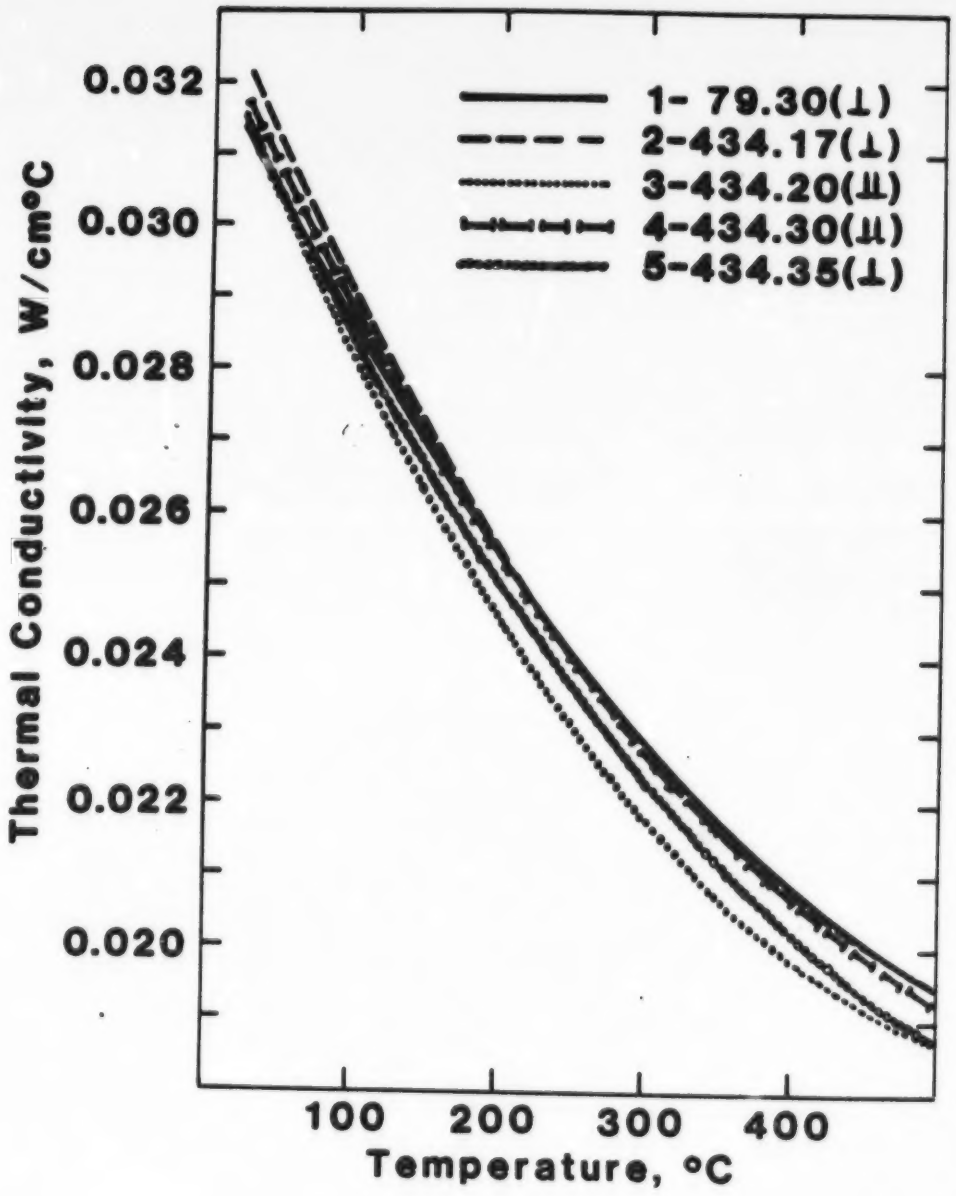

Figure 1. Thermal conductivity of ATK-1 drill core specimens from levels close to the surface. Symbols (∥) and (⊥) indicate that the cylindrical specimens were cut parallel or perpendicular to the axis of the drill core, respectively.

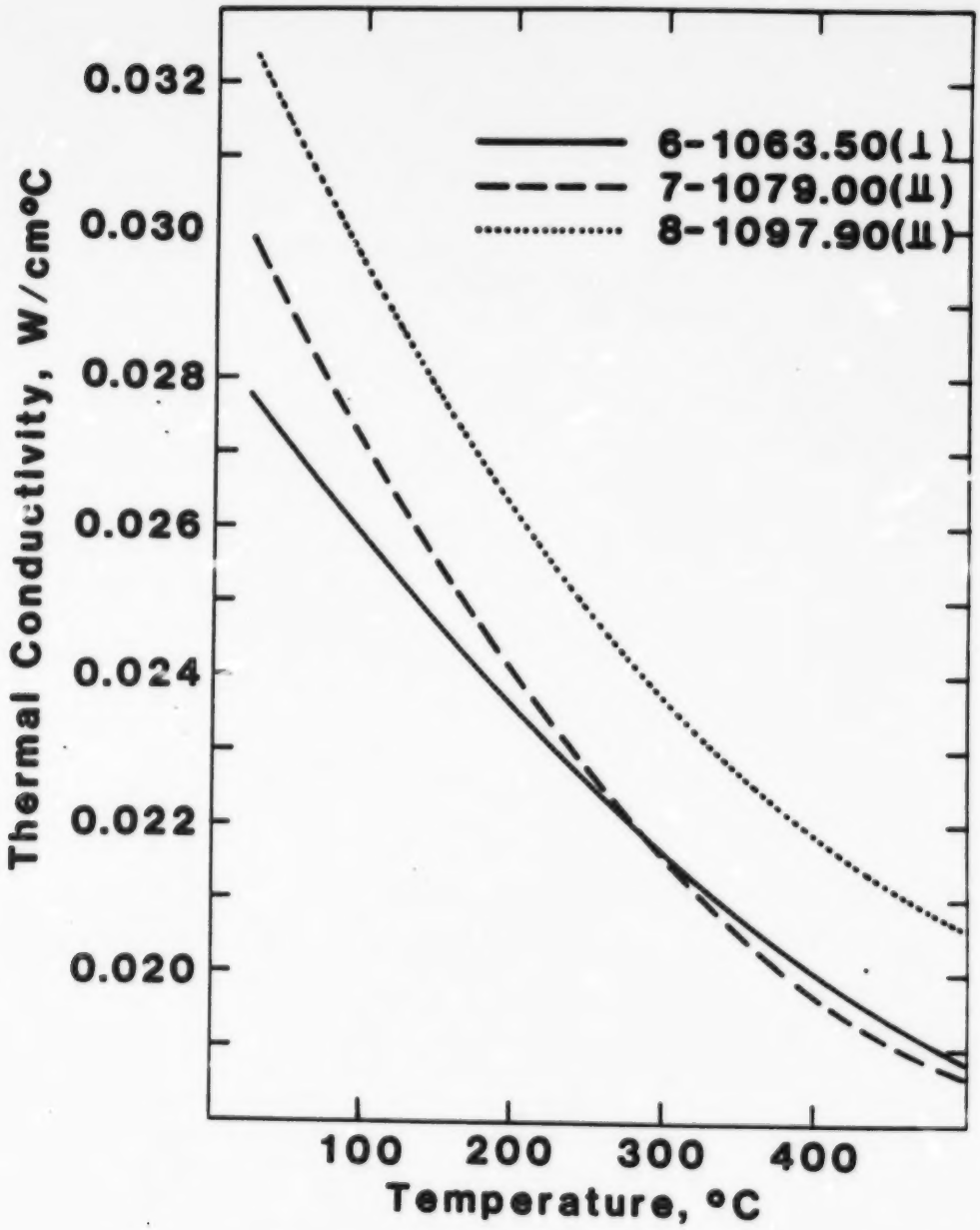

Figure 2. Thermal conductivity of ATK-1 drill core specimens from the deepest levels of the borehole. Symbols (∥) and (⊥) indicate that the orientation of cylindrical specimens was parallel or perpendicular to the axis of the drill core, respectively.